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MAGNETOSPHERIC SPACE PLASMA INVESTIGATIONS

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by

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INTRODUCTION

Under this grant we have carried out a number of studies on several different topics. We have presented the results to the scientific community at many different meetings and documented them in scientific journal publications. We have also discussed the preliminary results in some detail in our progress reports. We therefore limit the discussion below to a summary of important accomplishments. The last sections are listings of the publications and presentations resulting from the research supported in whole or part by this grant.

Among the significant accomplishments were the completions of UAH Ph. D. dissertations by Drs. David Brown, Chi Wing Ho, Joyce Lin, and Xinbo Zhang, each carrying out research partially supported under this grant. The Ph. D. degrees were all conferred in December, 1993. Titles of the dissertations were:

David Brown - *A Generalized SemiKinetic (GSK) Model for Mesoscale Auroral Plasma Transport*

Chi Wing Ho - *The High-Altitude Polar Wind: Simulation and Observation*

Joyce Lin - *Equatorial Heating Effects on Outer Plasmasphere Evolution*

Xinbo Zhang - *Ray Tracing Study of Magnetospheric ULF Wave Propagation*

More than 14 papers have resulted from the research leading to these dissertations, as well as many presentations to national and international scientific meetings.

SCIENTIFIC INVESTIGATIONS

Generalized SemiKinetic (GSK) Model

In one of several studies under this topic, we compared the H+/electron polar wind expansion into near-vacuum and the evolution of density perturbations, in the form of altitude-localized density cavities and enhancements, for the hydrodynamic and semi-kinetic models. In general, we have found that there is significantly less tendency to form shocks and steep gradients in the semikinetic model than in the hydrodynamic model; owing to ion velocity dispersion, such steep gradients tend to dissipate in the semikinetic description. We also found increasing divergence between the two approaches generally as higher moments are considered; in particular, the parallel temperatures often deviate significantly. The general subject of hydrodynamic versus semi-kinetic modeling results is of significant interest currently, and we believe this work will be of substantial importance. It has been found, for the types of outflow situations considered, that the inclusion of heat flow has a major effect in bringing to closer agreement the parallel temperature profiles for the hydrodynamic and semikinetic models.

Another interesting semikinetic study which we completed concerns steady-state profiles of polar wind densities matched with the DE-1 total density profile of Persoon et al. In this study, we used densities and drift velocities from low-altitude (2000-4000 km) polar wind observations of Chandler et al. as exobase O^+/H^+ parameter inputs for our semikinetic simulation. We found that if the combination of assumed base ion and electron temperatures is around 14,000 K (e.g., T_e=9000 K, T_i = 5000 K), the resulting polar wind steady-state density profile is dominated by O^+ to beyond 8 R_E, and that we obtain a virtually perfect match with the power law profile n_e = 490 $r^{-3.85}$ cm^{-3} observed in electron densities by Persoon et al.

We also completed development of a dynamic semikinetic model for examining the synergistic effects of waves and magnetospheric hot plasma populations on outflowing ionospheric plasma. This was done by imposing hot bi-Maxwellian ion and electron distributions at the top of our auroral simulation flux tube(4 R_E), as well as a spectrum of waves with altitude which perpendicularly heat the ionospheric ions. For example, when the hot ions are more strongly peaked at α = 90° than the hot electrons, a positive potential develops at the top boundary, hence downward electric fields. We then assumed a distribution of electric field wave power spectra along the magnetic field lines which produced ion perpendicular velocity diffusion, and allowed the ionospheric plasma to flow in from the bottom. With the perpendicularly-peaked hot ions producing a downward electric field, H^+ was energized to about 120 eV. We also saw a population of large downward fluxes of ~50 km/s H^+ which were trapped between the downward electric field above and the heating and upward mirror force region below. This situation thus represents a partially self-consistent dynamic model for the "pressure cooker" concept for energizing conics.

O^+ Outflows

A systematic study of the effects of $\mathbf{E} \times \mathbf{B}$ convection heating on O^+ upflows in the high latitude F-region ionosphere was carried out. Simulation cases were performed for both solar minimum and solar maximum atmospheres for values of the convection electric field ranging between 50 and 200 mV/m. Results of this study were compared with similar studies done with hydrodynamic and generalized transport models and important differences were noted. These study results were also compared with radar and satellite data, and good agreement was found with some of the data

We completed a study of the quasi-statistical properties of outflowing O^+, through bulk parameter analysis of DE-1/RIMS observations when DE-1 was in the midaltitude polar cap magnetosphere. We employed a technique which relies on analysis of the DE-1 radial head RPA data near the magnetic field direction for obtaining the O^+ bulk parameters of density, temperature and flow velocity from these measurements. We analyzed thirteen passes and tested our technique with reasonably good confidence in the derived parameters.

A study examining the centrifugal acceleration effects on the polar wind was also completed. It was shown that for an exactly polar field line, the outward ion acceleration is given by

$$a= 1.5(E_i/B_i)^2(1/r_i^3)r^2$$

We found that for a 50 mV/m ionospheric convection electric field, the steady-state O^+ bulk velocities increase from near 0 km/s at 4000 km altitude to about 10 km/s at 5 R_E geocentric, which is in reasonable agreement with previous observations of large O^+ outflow velocities. The centrifugal force further has a pronounced effect on the escaping O^+ flux, especially for cool exobase conditions.

Field-Aligned Flows and Trapped Ion Distributions

We completed a statistical study of the latitudinal distributions of core plasmas along the L=4.6 field line using DE-1/RIMS data. We studied those orbits for which the spacecraft was approximately skimming this L-shell, and for which the low-energy ions were trapped distributions at the equator and counterstreaming off the equator. We analyzed approximately 40 such orbits, and characterized parameters such as the ratio of equatorial-trapped to 45° flux or equatorial anisotropy, the latitudinal half-width of the anisotropy, the transition latitude where ions exhibit significant anisotropy, the penetration ratio of field-aligned fluxes in the vicinity of the equator to outside the transition, and the latitudinal scale length of the trapped ion flux variations near the transition latitude. Various types of occurrence frequency relationships have been deduced. Perhaps the most interesting result is that we find an inverse relationship between the equatorial anisotropy and the penetration ratio. This is understood as the result of enhanced positive electrostatic potential associated with increased ion equatorial anisotropy producing a reduced equatorial penetration of the field-aligned ions.

We also carried out a study of semikinetic modeling of the effects of equatorial heating and electrostatic hemispheric decoupling on early L = 4 core plasma evolution. In this study, we considered asymmetrical northern/southern hemispheric ionospheric flows and incorporated a generalized transport description for the electron population, which allowed for consideration of electron heating effects and a more realistic calculation of electric fields produced by ion and electron temperature anisotropies. The combination of equatorially-concentrated perpendicular ion heating and parallel electron heating led to an electrostatic potential peak about the magnetic equator which tended to shield and decouple ion flows in the northern and southern hemispheres. Unequal ionospheric upflows in the northern and southern hemispheres led to development of distinctly asymmetric densities and other bulk parameters. Termination of particle heating caused the reduction of equatorial potential and allowed interhemispheric coupling. When the inflows from the ionospheres were reduced (as may occur after sunset), decreases in plasma density near the ionospheric regions were observed, while the heated trapped ion population at the equator persisted.

ULF Wave Ray-Tracing

Another study which was completed was the examination of the effects of heavy ions on the propagation of ULF waves in the dayside magnetosphere. We had previously seen the effects of O^+ on Pc3 fast mode waves, due to the cutoff between the He^+ and O^+ gyroresonances. The same effect was found for Pc1 waves due to the H^+-He^+ cutoff. The difference is that the O^+ concentration is much more variable than the He^+ with solar and geomagnetic conditions. Interestingly, it was found that for a given frequency, if the O^+ concentrations were raised sufficiently high, the location of the O^+ barrier is pushed beyond the magnetopause. In that case, Pc3 waves, which are thought to originate at the magnetopause, would then have greater access to the inner magnetosphere. Observations by the AMPTE CCE satellite indicate that the O^+ concentrations required for this to happen, while not typical, are not really uncommon. If this is the case, then to the extent that solar and geomagnetic conditions modulate the O^+ concentration throughout the magnetosphere, energy transport by means of ULF waves may likewise be modulated.

The effects of heavy ions (O^+ and He^+) seen in the propagation of Pc1,2 and Pc3 fast mode waves were also seen in Alfven mode waves. Since these waves are constrained to travel along magnetic field lines, deeper penetration toward the Earth also means propagation to higher latitudes. In addition, the different nature of the waves makes interpretation of the wave propagation more complex.

Plasmasphere-Ionosphere Coupling

A short study was carried out on heating processes in low density flux tubes in the outer plasmasphere. The purpose was to determine whether the high ion temperatures observed in these flux tubes were due to heat sources operating through the thermal electrons or directly to the ions. In the case study we performed, results clearly indicated that only direct ion heating was capable of producing the observed ion temperatures. However, consequences of this heating included ion temperatures at low altitudes which far exceeded observations, as well as ion composition at high altitudes with concentrations of heavy ions (particularly O^+) which also greatly exceeded observed levels. We suggested that these effects might be due to too much heat being conducted to low altitudes, due to the very high thermal conductivity under the low-density, high-temperature conditions being simulated.

To test this we then carried out an initial study of thermal conductivity in a low density plasma flux tubes. In this study we proposed that when ion mean free paths extended from the location of interest to or beyond the ionosphere, only those particles in the loss cone would be effective transporters of heat out of the plasmasphere, since other particles would be trapped and retain the heat within the plasmasphere. We derived a simple mathematical model to represent this situation and applied it in place of the standard Spitzer-Harm thermal conductivity coefficient. Heat conduction was significantly reduced, so that less heat was required in the simulations to raise ion temperatures at high altitudes to observed levels, simulated temperatures at low altitudes were lower, and simulated concentrations of O^+ at high altitudes were reduced to levels much closer to those observed.

ANALYSIS TECHNIQUES AND SOFTWARE DEVELOPMENT

Empirical Model

DE1/RIMS automated data analysis procedures for the empirical model had been basically completed in prior work. In collaboration with NASA scientists in the empirical model group, we carried out a systematic analysis of experimental uncertainties and error propagation through the automated analysis procedure. We also examined temperature differences between the RIMS end heads and concluded that systematic differences between the temperatures determined by the different heads are a larger source of uncertainty than those associated with scatter in the data. The magnitude of these differences vary with plasma conditions in ways that are not yet predictable and, hence, cannot be rectified with assurance. Final changes were made to the automatic processing methods and data output formats. Large scale testing was carried out, and was found satisfactory for comprehensive analysis of the RIMS data set.

The completed automated processing code was used to process RIMS data from 1981 to 1984, and we began examining the resulting data base. One significant result is that on average the heavy ions (O^+) are basically in thermal equilibrium with the light ions (H^+ and He^+). In looking at the available data, we find that for low solar activity ($F10.7 < 120$) there are very few observations at low L-shells (<2). Those that do exist appear to show signs of detector degradation, i.e. temperatures are unrealistically high and densities are unrealistically low. Mean values for medium and high solar activity appear to be consistent with one another and with expectations from previous observations, although large standard deviations indicate wide variations. Initial analysis has been incorporated into the empirical total plasma density model.

HARDWARE

We participated extensively with NASA scientists in testing, modifying, assembling and calibrating the flight hardware for the Thermal Electron Capped Hemisphere Spectrometer (TECHS) experiment. This instrument was successfully flown on the Sounding of the Cleft Ion Fountain Energization Region (SCIFER) rocket flight on January 25, 1995, from the Andoya Rocket Range, Norway and the instrument performance was outstanding, according to the PI (C. J. Pollock).

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